Renewable and Sustainable Energy Reviews 24 (2013) 45–56

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Analysis of energy transition possibilities after the decommission of a nuclear power plant in Ignalina region in Lithuania

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ARTICLE INFO

Article history:
Received 21 December 2012
Received in revised form
7 March 2013
Accepted 15 March 2013
Available online 10 April 2013

Keywords:
Energy demand
Renewable energy sources
Energy transition

ABSTRACT

The article describes the Lithuanian energy policy, energy and economical problems before and after the decommissioning of Ignalina nuclear power plant (INPP). After the decommission of INPP, the dominant kind of primary energy in the region became a imported natural gas which amounted to 74.8%, wood and waste provided 22%, and imported heavy fuel oil brought 3.2% of the primary energy. In the article the generation possibilities of electricity and heat from the renewable energy sources (RES) in INPP region are shown, technical and economically-based potentials of solar heat and solar electricity are evaluated, technical potential of wind power plants is disclosed, the potential of wood fuel use is predicted, theoretical possibilities of shallow geothermal energy use are revealed. The calculated total technical potential of RES usage in the region is around 30.1 thousand tonnes of oil equivalent (toe), from which wood fuel amounts to 14.7, wind power—11.3, solar heat and photo electricity—3.3, and hydro energy—0.8 thousand toe. INPP region consists of Ignalina and Zarasai district municipalities and Visaginas town municipality. In Zarasai and Ignalina districts, RES potential is 11.5 and 11.3 thousand toe, respectively, and Visaginas town potential is around 7.3 thousand toe. The measures to be taken to achieve the set objectives in Lithuanian INPP region are analyzed in this article.

Contents

1. Introduction

About 30 years Lithuanian Ignalina and Zarasai countries with Visaginas town were related with Ignalina nuclear power plant (INPP) [1]. According the requirements of European Union (EU), for

Abbreviations: CHP, Combined heat and power; EU, European Union; HPP, Hydro power plant; INPP, Ignalina nuclear power plant; JSC, Joint Stock Company; LEI, Lithuanian Energy Institute; NPP, Nuclear power plant; PEA, Public energy alternatives; RES, Renewable energy sources; toe, tones of oil equivalent; TW h, tera watt hour (tera—10^{12}); W, watt (electrical power unit)

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http://dx.doi.org/10.1016/j.rser.2013.03.028

the usage of unsafe technologies, such insecure plant was decommissioned and yet 30 years will be dismantling. The unexpected demand of the EU to develop a program of rapid closure of the INPP—the cheapest source of electricity throughout the region was the condition for the Lithuanian membership in the EU. The main argument for this demand was that nuclear power reactors in Lithuania were the same type as in the Chernobyl NPP and according to western experts cannot be considered safe. Lithuania agreed with the requirement that membership of Lithuania in the EU is possible only if the Ignalina nuclear power plant will be closed within a predetermined period of time. The deadlines were set that the first of two working INPP block units would have to close by the end of 2004 [2] and the second block—by the end of 2009 [3].

INPP Region was founded in 2002 after the EU requirements and decisions for decommissioning unsafe INPP [4]. The forces of the region municipalities were concentrated for the solution of common problems and INPP Regional Development Agency was established. The region development program was formulated and gradually implemented by applying the EU structural funds. But, despite all efforts to soften the sub-sequences of decommissioning of a nuclear plant, the prices of energy increased, the unemployment overgrew, trades were disappearing, and the level of emigration increased. The largest decline and heaviest consequences will be felt in Visaginas town municipality. From the start of operation INPP till the 31st of December 2009 it provided the residents, institutions and enterprises with waste heat from power generation. The residents were granted the benefit of "protected" electricity price equal to 50%. Upon the shutdown of INPP the heat prices and services increased significantly: heat prices—4 times, hot water price—2 times. It caused the social shock in the municipality and continues to negatively affect the life quality of population and activities of public-spending entities (budgetary authorities). The sharp increase in prices leads to the extended amount of compensations to be paid out for residents. All these factors induce the migration to other districts and abroad. The Lithuanian national and regional interests were to stabilize the emigration processes, to return the attraction of country and provide people with the possibilities to create the welfare on their land.

The major impact on energy policy in Lithuania on such time had preparation for accession to the European Union. It was necessary to harmonize the Lithuanian energy policy with EU policy and with a number of binding directives. Undoubtedly, the fate of the Ignalina nuclear power plant, the source of the cheapest electricity, which provided nearly 80% of the country's electricity supply, had a special impact on future of the electricity sector in all Lithuania. In order to prepare a more or less reliable and realistic strategy for the period after shutdown of INPP, it was necessary to conduct a thorough modelling of the most probable scenarios for the future development of the energy sector, taking into account not only the closure of the INPP, but also possible developments in international energy markets, actions and plans of Lithuania's neighbours. It was necessary to forecast the overall development of the economy and thus the future demand for energy resources. The analysis of all possible scenarios was carried out by the experts of the Lithuanian Energy Institute (LEI) on Lithuanian National Energy Strategy 2007 [5]. Some of the most important strategic objectives outlined in such strategy should be highlighted. They were: (1) energy security, (2) efficient use of energy; (3) introduction of competitive principles in the energy sector; (4) gradual integration into the energy systems of the European Union; (5) diversification of primary energy sources and ways of their imports, the rapid increase of renewable and local energy resources, and reducing the share of natural gas in the energy mix in Lithuania.

In order to achieve these objectives, the most important following activities were identified:

1. Implement the EU directives on the liberalization of electricity and natural gas markets;
2. Create a common electricity market of the Baltic countries and continue to integrate with the EU markets;
3. Ensure continuity in the use of nuclear energy by building a new nuclear power plant capable of ensuring the needs of all three Baltic States and the region;
4. Connect the electrical transmission network of Lithuania with the networks of the Nordic countries and Poland;
5. Ensure compliance with the EU directives related to the accumulation of reserves of oil and natural gas;
6. Increase the share of renewables in the primary energy balance up to 20% by 2025. Increase the share of electricity produced at cogeneration power plants up to 35%.
7. Continuously improve the consumption efficiency of all types of energy, so that by 2025 it would be possible to achieve the efficiency levels of developed countries of the EU.

The Directive 2009/28/EC on the promotion of the use of energy from renewable energy sources (RES) sets the overall target to reach 20% renewable energy in gross final energy consumption in 2020 [6]. This target is bind with individual Member State targets. Energy consumption from RES in 2005, progress in 2010 and targets for 2020 years for Lithuania and the EU-27 are shown in Fig. 1, [7].

The Lithuanian target is to increase the share of renewables in gross final energy consumption from 17 to 23% to 2020. Reaching these targets will require a huge mobilization of investments in renewable energies not only for Lithuania but also for all EU 27 countries.

As shown in Fig. 1, the targets on the share of RES in final energy consumption in Baltic Sea Region countries are quite different. While Finland and Latvia already had a share of around 30% in 2005, Poland and Germany shares were below 10%. Thus the range of increasing the share of RES of such countries varies from around 20% (Latvia) to 200% (Germany). The Lithuanian range of increasing the share of RES is around 35%.

In Lithuania, the possibilities of wider use of local fossil resources (oil, peat) are limited. Therefore, it is extremely important to use the RES as widely as possible. The development of RES will ensure an attractive alternative to traditional energy because the combustion of fossil energy sources substantially increases the environmental pollution [8]. The sector of RES became the driving force of the country's economy. The goal of Lithuania is that sector of RES would fully satisfy the country's demand for heating and electricity would be produced at power plants that are neutral in terms of carbon dioxide. The use of RES in Lithuania is increased so as meet economical conditions of our country as well as in other countries [9]. Other countries also increasing to use renewable energy technologies and taking positive steps towards carbon emissions, cleaning the air and ensuring a more sustainable future [10]. The coming sustainable energy transition in the world, its history, strategies and outlook were analyzed by USA specialists [11]. The transitions from traditional to sustainable energy development for developing countries were studied in [12].

This article on RES implementation possibilities in Ignalina NPP region was prepared using the LEI material, collected and analyzed by implementing the Baltic Sea Region 2007–2013 programme project PEA "Public Energy Alternatives—Sustainable energy strategies as a chance for regional development" [13]. It is partially EU-funded project through which the RES are to be promoted as a driving force for business, technology, and engineering in the whole Baltic Sea Region. Twenty-one partners from six countries (Estonia, Finland, Germany, Latvia, Lithuania, and Poland) around

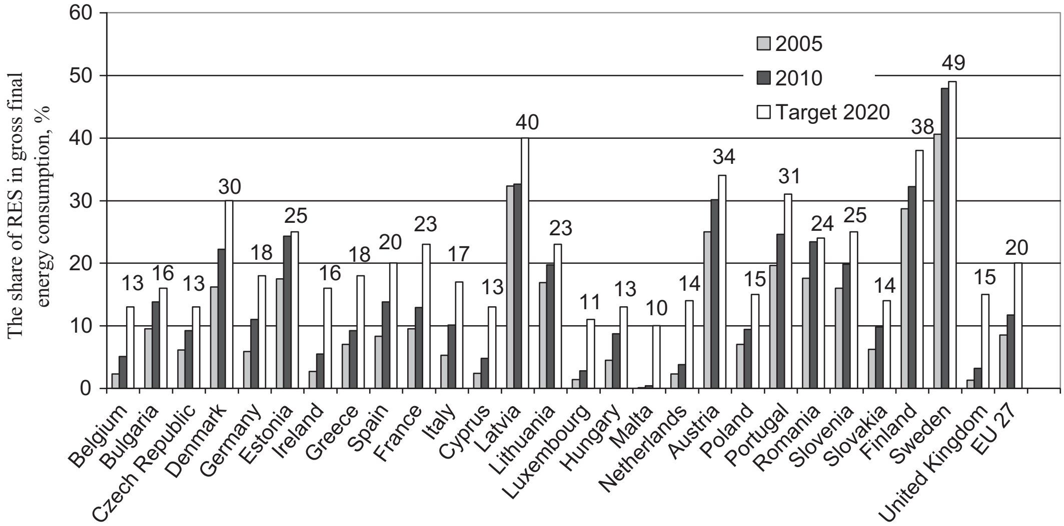


Fig. 1. The share of RES in gross final energy consumption in 2005, progress in 2010 and targets for 2020 years for Lithuania and other EU-27 members.

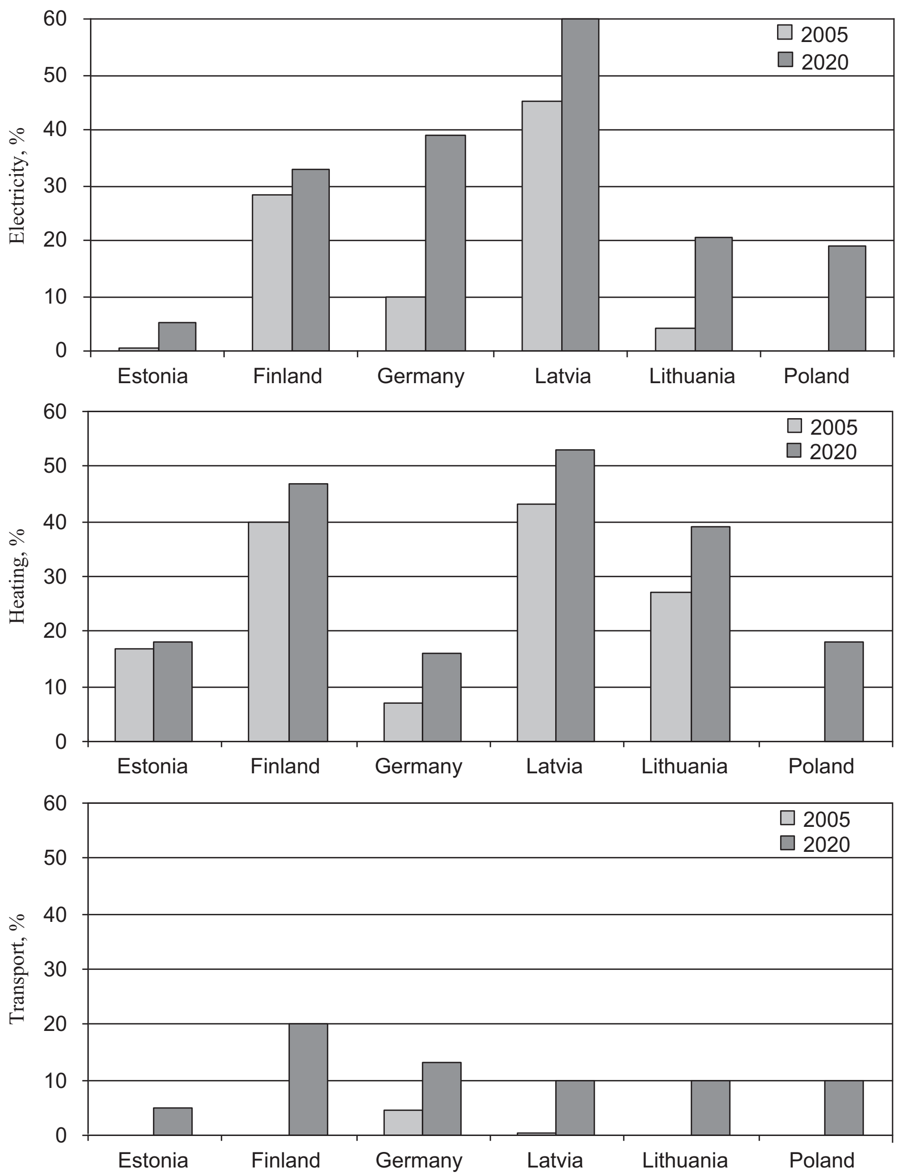


Fig. 2. The share of final energy consumption from RES on *electricity, heating* and *transport* sectors for Lithuania and other Baltic Sea Region countries implementing the PEA project.

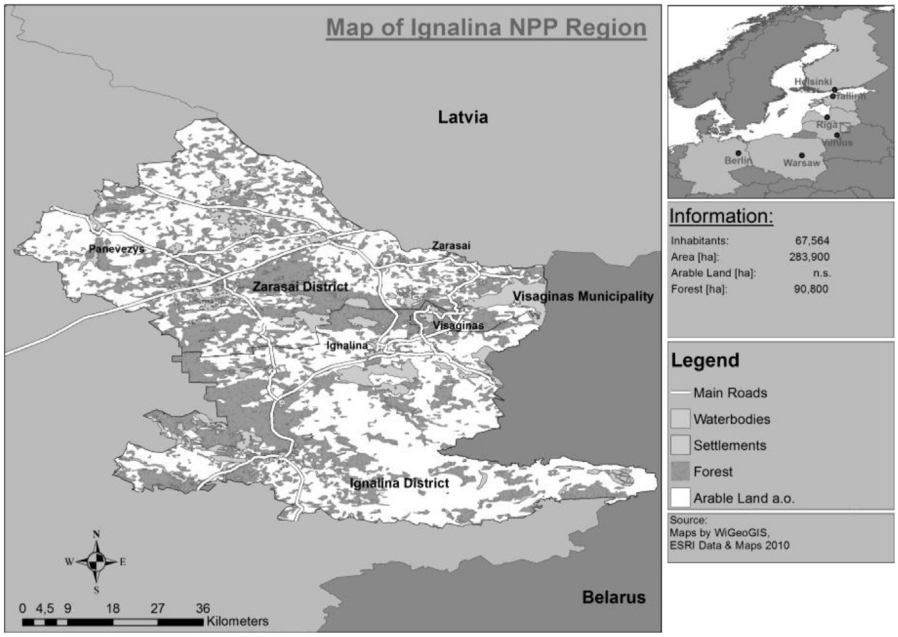


Fig. 3. Map of the Ignalina nuclear power plant region.

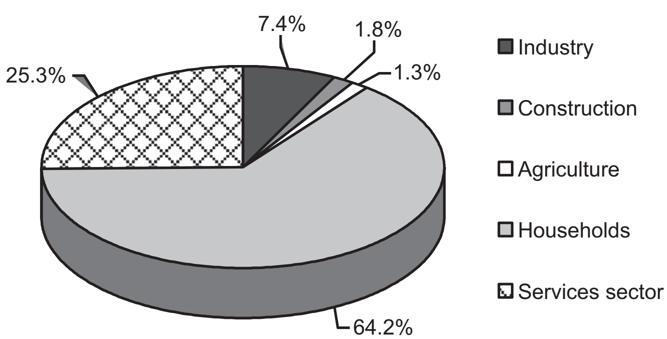


Fig. 4. Final energy consumption by economy sectors in Lithuanian INPP region in 2008.

the Baltic Sea together with experts from various scientific areas of expertise are trying to show that potential energy saving capacities exist that can be tapped into, strengthened and expanded. Article 4 of the renewable energy Directive (2009/28/EC) requires EU Member States to submit national renewable energy action plans, provide detailed roadmaps of how each Member State expects to reach its legally binding 2020 targets for the share of renewable energy in their final energy consumption. The basic information on PEA project work directions and achievements was published in 2011 on Lithuanian "Thermal Technology" journal [14,15]. Expected targets for RES in final energy consumption in *electricity, heating* and *transport* sectors for such implementing PEA project countries, according to each national renewable energy action plan, are shown in Fig. 2, [16]. *Electricity* generated from RES in Latvia, from 2005 to 2020, should increase from 45 to 60%, in Finland—from 27 to 33%, in Germany—from 10 to 38%, in Lithuania—from 4 to 21%. The 2020 targets on RES for *heating* in Latvia is 53%, Finland—47%, Lithuania—39%, Germany—15%. The share of RES in *transport* on 2020 should reach 20% in Finland, 13% in Germany and by 10% in Latvia, Lithuania, and Poland.

Energy Policy and Strategy of Lithuania in 1990–2010 and projections for the future were analyzed in detail by authorities of LEI [17]. Comparative assessment of policies targeting energy use efficiency in Lithuania was made in article [18]. The tendencies of renewable energy usage and policy in Lithuania were analyzed in [19]. Promotional policy and perspectives of using renewable energy in Lithuania till 2005 were described by experts in [20]. Governmental policy and prospect in electricity production from renewables in Lithuania till 2008 were outlined by LEI specialists in [21]. The Lithuanian general strategic guidelines, objectives, and vision of energy sector until 2050 are disclosed in National Energy Independence Strategy of 2012 [22].

2. Ignalina NPP region and current energy situation

Ignalina NPP region is situated on the Eastern part of Lithuania near the border with Latvia and Belarus and consists of Ignalina and Zarasai district municipalities and Visaginas town municipality (Fig. 3).

In Ignalina and Zarasai district municipalities, the biggest part of economic activities were related to service sector (67–73%), industrial sector 15–23%, agriculture, hunting and forestry—around 5%, construction sector—5–6% of overall economy structure.

Visaginas town was constructed as the centre of electricity production in the INPP. Other industry branches, i.e. construction, wood processing and others, were developed to meet the needs of the INPP and were not developed in the latter years. There were no other big enterprises in the INPP region, except from the nuclear power plant. INPP was one of the principal strategic objects of the Visaginas town municipality; before the decommissioning in 2008–2009 the plant produced about 71% of the electricity necessary for Lithuania [23,24].

In 2008, the final energy consumption in INPP region was 55.89 thousand toe, (around 650 GW h/year). About 25.3% of final energy consumption belonged to service sector, 64.2%—to households, 7.4%—to industry and 3.1%—to construction and agriculture (Fig. 4) [25].

About 47% of total final energy consumption belonged to Visaginas town municipality and 26–27%—to Ignalina and Zarasai districts. Final energy consumption by economy sectors in municipalities of INPP region are shown in Fig. 5.

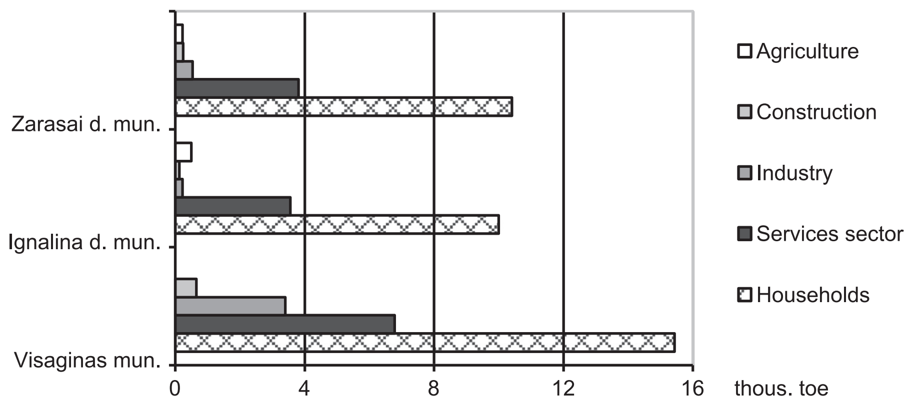


Fig. 5. Distribution of final energy consumption by economy sectors in municipalities of INPP region in 2008.

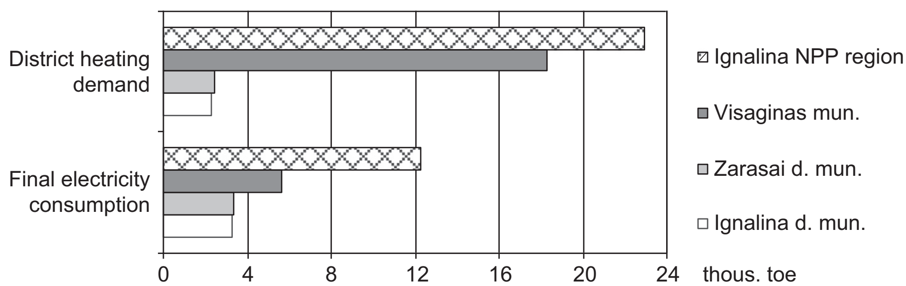


Fig. 6. District heating demand and final electricity consumption in INPP region and its municipalities in 2008.

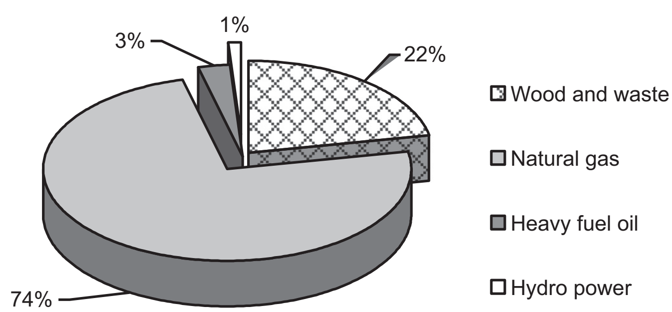


Fig. 7. Total primary energy supply in the INPP region in 2010.

Table 1
Generation of thermal energy and RES contribution in the INPP region, thousands of toe.

	Thermal energy demand (thousand of toe)	Generation from RES (thousand of toe)	RES contribution (%)
Ignalina district municipality	9.86	9.86	100
Visaginas municipality	57.30	1.42	2.48
Zarasai district municipality	7.58	5.95	78.50
INPP region	**74.74**	**17.23**	**23.05**

In all municipalities final energy consumption was higher in households (10–15.4 thousand toe) and next in services sector (3.6–6.8 thousand toe).

Final energy consumption in all INPP region households reached 35.84 thousand toe. About 43% of that amount belonged to Visaginas municipality and 28–29%—respectively to Ignalina and Zarasai district municipalities. The second according the size of consumption was services sector—14.15 thousand toe. About 48% of that value depended to Visaginas municipality, 27% to Zarasai and 25% to Ignalina district municipalities. For industry sector belonged 4.16 thousand toe, from which 82% depended on Visaginas municipality.

The district heating demand in INPP region was around 23 thousand toe in 2008. About 18 thousand toe depended on Visaginas municipality and 2.5 thousand toe—on Ignalina and Zarasai district municipalities (Fig. 6).

Final electricity consumption in INPP region was 12 thousand toe. About 46% of that value is consumed by Visaginas municipality and 27% by Ignalina and Zarasai district municipalities.

Decentralized energy demand for heating of premises in household and services sectors in Ignalina NPP region in 2008 were around 8 thousand toe, 55% of which depended on Ignalina district municipality, 43% on Zarasai district municipality and about 2% on Visaginas municipality. Energy demand for hot water preparation in the same economy sectors were around 1.4 thousand toe, 54% and 42% of which depended, respectively, on Ignalina and Zarasai district municipalities and about 4% on Visaginas municipality.

After the shutdown of the INPP, in 2010 the dominant kind of primary energy in INPP region became a imported natural gas which amounted to 74% (Fig. 7).

Wood and wastes brought 22% of primary energy in the region, imported heavy fuel oil—3% and hydropower—1% of the primary energy. The heat supply demand in the INPP region was around 74.74 thousand toe. About 57.3 thousand toe belonged to Visaginas town municipality, 9.86 thousand toe—to Ignalina and 7.58 Zarasai districts (Table 1).

About 23% of heating in the whole INPP region in 2010 was produced using RES: 78.5% in Zarasai district, 100% in Ignalina district and 2.5% in Visaginas town.

A new law on RES of the Republic of Lithuania sets a target to consume not less than 50% of district heating energy from RES till 2020 [26,27]. Thus, it is the best situation in Ignalina, while Zarasai requires minor improvements in the use of RES. By contrast,

Table 2
Generation of electrical energy by RES in the INPP region.

	Amount of elec. power consumed (thousand of toe)	Total amount of elec. power consumed (thousand of MW h)	Generation by RES (thousand of toe)	Generation by RES (thousand of MW h)	Percentage by RES (%)
Ignalina district municipality	3.01	35.01	0.05	0.58	1.66
Visaginas municipality	5.18	60.25	–	–	0.00
Zarasai district municipality	3.11	36.17	0.75	8.72	24.12
INPP region	**11.3**	**131.43**	**0.8**	**9.30**	**7.08**

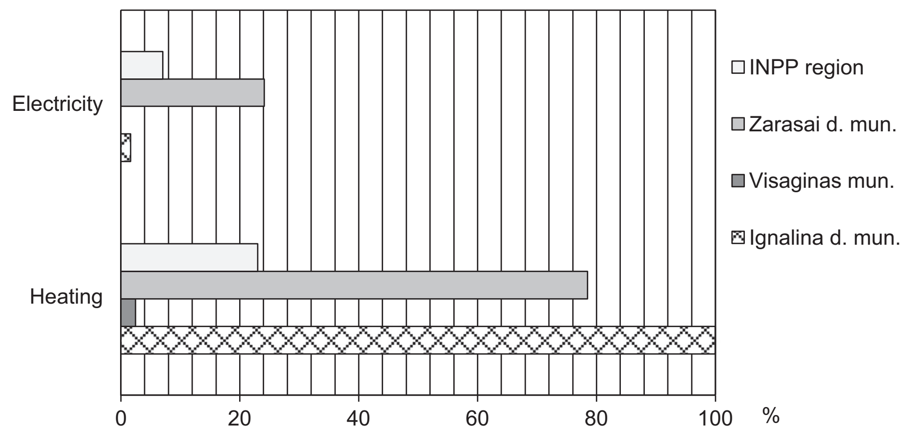


Fig. 8. The heat and electricity generation from RES in INPP region municipalities.

radical changes on use of RES in heating sector are necessary for Visaginas town.

Electricity energy generation by RES in the INPP region is shown in Table 2.

According to the new law on RES, no less than 21% of electricity should be generated using RES in Lithuania. This aim has already been reached in Zarasai district (24.1%). In Ignalina district municipality, electricity production from RES comprises only 1.7% and in Visaginas—0%. Therefore, Ignalina and Visaginas should be more active in introducing RES in their municipalities. Heat and electricity generation from RES in INPP region municipalities is shown in Fig. 8.

Energy-saving potential in the INPP region is also very high as it amounts to not less than 35%, taking into account energy loses in old buildings, industrial and domestic electricity appliances, and incandescent lamps. Thus, RES potential and possibilities to reduce energy consumption provide incentive to seek for 100% RES status of the INPP region in the future.

Distribution of energy by needs for electricity, heating and transportation in the INPP region are shown in Fig. 9.

The main part 84% of energy used in INPP region goes to heating needs, 12.7%—to electricity and 3.1%—for transportation.

Current power-related situation of the INPP region is satisfactory as per the relation of supply volume to the needs of inhabitants and operating plants. Almost the whole volume of energy comes from outside of the region, except for the existing installations based on renewable energy sources: biomass plants, solar panels and hydropower. The basic energy carriers are natural gas, electricity, as well as firewood and oil. The major part of fuel and energy consumed in INPP region, as in all Lithuania is imported. However, having shutdown INPP, Lithuania is no longer able to suitably satisfy its energy demand. Energy dependency increased from 50.18% in 2009 to 81.92% in 2010. Electricity networks are not connected to the European electric power systems, for this reason, the electric power may be imported only from several countries. Therefore, it is natural that the share of electricity generated using renewable energy sources is expected to increase up to 17% in the balance of electricity generation of 2015. Due to the above-mentioned circumstances, very favourable conditions emerge to notably increase the use of biofuel in the companies supplying centralized heating by reducing the share of natural gas, respectively.

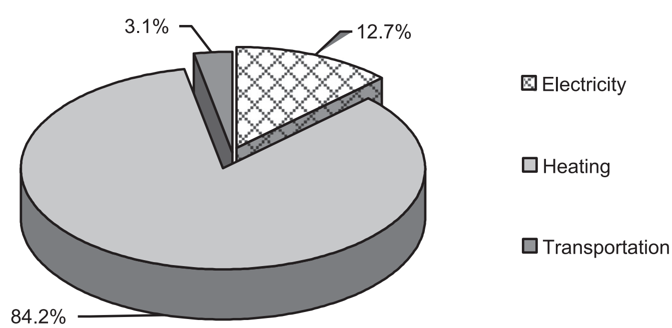


Fig. 9. Distribution of energy used in the INPP region by sectors.

3. Analysis of energy-saving possibilities in INPP region

A large share of the consumed final energy pertains to heating energy, whereas in dwelling and public buildings a greater share of heating energy goes to heating the premises. In the industrial sector, it usually pertains to heat related to technological processes. In addition, the industrial sector has considerable possibilities to save energy by using the waste heat; however, the estimation of such possibilities requires separate analysis of each

company according to the types of production. Moreover, not all companies are open throughout the year as some of them work only periodically depending on the received orders. For this reason, it was decided not to carry out the calculations of energy saving in the industrial sector.

Additional thermal insulation of envelopes, replacement of windows and doors or their tightening, and mounting of heat reflective screen behind the radiators have a great influence on heat losses in buildings. Not only additional insulation of buildings, but also the renovation of heating system can reduce the heat losses.

When the central heating supply systems are used, it is important to build heating stations with automated temperature control and accounting. In the towns of the INPP region, such heating stations were built in most of the blocks of flats. Not only the installation of automated accounting for the whole house, but also for each flat separately together with thermostatic valves would be especially useful for energy saving; however, they were installed only in the newly-build houses. One- or two-storey private houses, or blocks of flats built before 1995 do not meet the requirements of thermal resistance; thus, they have a great energy-saving potential. On average, it may be estimated that, applying the all possible energy saving measures, would be able to save about 30–40% of heating energy in the living premises. But the consumers will not probably apply all possible energy saving measures in their homes because this would require great financial resources. The measures providing instant benefits and improving the quality of the living premises should be applied first. Thus, more real theoretical heating energy saving potential in INPP region would be about 25% of final heating energy consumption. In the whole INPP region, this could comprise about 90,000 MW h/year from the final heating energy consumption 360 MW h/year (Fig. 10).

In order to exactly estimate electrical energy savings in separate economic sectors, energy-saving projects should be prepared for each object or building by evaluating their specificity and equipment using electricity (technical level) and then the results should be summed up. However, this would be a detailed assessment of energy saving which requires a lot of time and efforts. An approximate assessment of saving possibilities, which deals with average percentage of saving by installing several saving measures, is also possible. Such method was used to assess saving possibilities; thus, the average electrical energy-saving potential in the INPP region reaches about 28%.

According to the data of 2008, the annual final electrical energy demand in the INPP region amounts to 142,700 MW h. Around 46% of this amount was used in Visaginas municipality and 27%—in each Ignalina and Zarasai district municipalities.

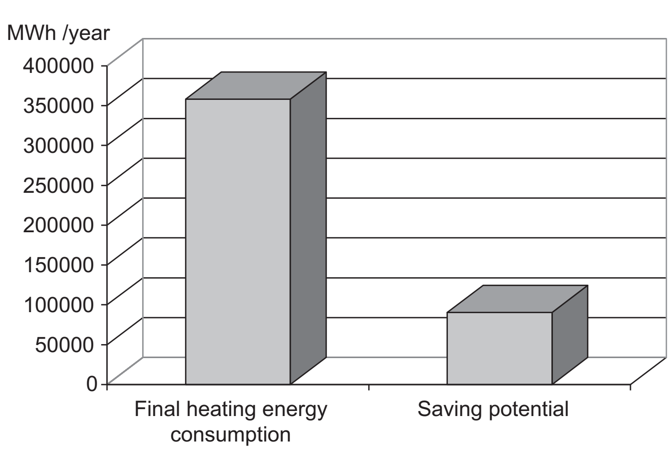


Fig. 10. Theoretical heating energy saving potential in INPP region.

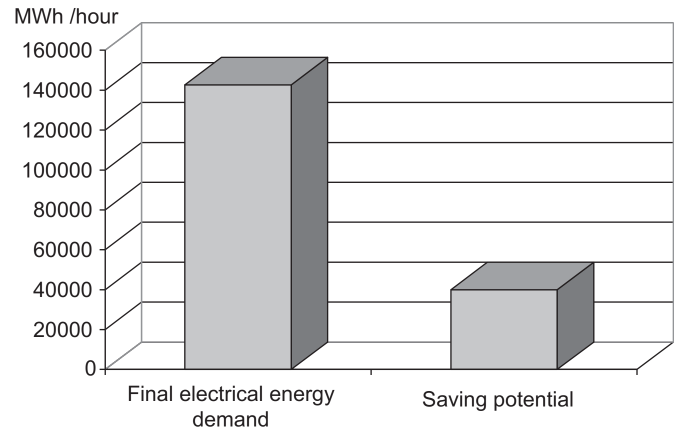


Fig. 11. Theoretical electrical energy saving potential in the INPP region.

Theoretically, the saving potential in the whole INPP region could reach about 40,000 MW h/year (Fig. 11).

In public buildings, the biggest share (50% and more) of electrical energy is used for lighting. In some public buildings, expenses for lighting may even exceed the costs of heating. For this reason, the resources of saving are related to appropriate regulation of general and local lighting as well as the use of economical light bulbs. It is important to mention that economical light bulbs have already been introduced to the majority of public buildings; hence, in this case other measures could also be applied to increase saving, for example: the lamps could be lowered down; the light could be turned off automatically when there are no people in some premises; the lighting of areas around the buildings could be automatically controlled using motion or lighting sensors.

Other electrical energy receivers in public buildings are ventilation systems, lifts, water pumps and conditioners. Due to imperfect characteristics, wrong operational mode, inappropriate operational conditions and non-adjusted parameters of systems and electrical engine, electrical energy is very often consumed inefficiently and unreasonably. The application of the mentioned measures would save up about 22% of electrical energy.

In households, when electrical appliances are not used for heating the water and cooking, electrical energy is mostly required for lighting, televisions, irons, washing machines, vacuum cleaners or refrigerators.

A great deal of possibilities to save electrical energy exists in households. The majority of citizens still own uneconomical Soviet-made refrigerators and use them inappropriately due to the lack of knowledge, which increases the outlay of electrical energy even more. If they were replaced with up-to-date, energy-efficient and economical refrigerators which would be properly used, it would be possible to save up about 20–25% of electrical energy required for these appliances. A vast amount of electrical energy could be saved by installing economically efficient up-to-date lighting in houses. Currently, the greatest share of light sources in households is ordinary incandescent light bulbs. Replacing them with energy saving light bulbs would make it possible to save up to 70–80% of energy used for lighting.

Industrial sector has rather large reserves for electrical energy saving and increasing its efficiency. Therefore, in recent years, a great deal of attention has been directed towards this, especially by private companies. The measures for electrical energy saving may be applied in almost all industrial companies: in compressors and compressed air systems, ventilation systems, lighting installations as well as for the compensation of reactivity power.

4. Analysis of RES potential

4.1. Lithuania's RES installed technologies

In Lithuania, there are used such kinds of RES, which are traditional for our country as firewood, wood waste, straw, hydro energy as well the RES projects that have the shortest payback time (wind energy, biogas, etc). There are erected pilot projects of geothermal energy, solar energy and other ones. RES are used for production heat, electricity and biofuels for transport as well as in other countries [28].

4.1.1. Heat production

The heat in Lithuania is produced by solid biomass (firewood, wood waste, straw, etc) and by geothermal energy and also other fuels [29]. The main part of heat energy is produced in a big district heating systems that operate in all major cities and in many smaller towns. At present time, the total capacity of wood-chip-fueled boilers reached above 476.1 MW [30]. No serious obstacles can be seen for extension of wood fuel usage. Also, the straw as fuel is used for heat production. There are erected some boiler houses for the combustion of these fuels. The installed capacity of straw combustion boilers reached 12.8 MW in 2010.

In Lithuania, there is a pilot geothermal energy plant which produced about 0.27 TW h/year of energy. The construction was completed in year 2001. At present time such plant is working on total capacity about 17 MW. It supplies heat for the district heating network of Klaipeda town. The small geothermal pumps (capacity of 15 kW and 18 kW) are used for heating of small houses and technological processes in small companies. The total installed capacity of the geothermal pumps was 31 MW in 2010.

4.1.2. Electricity production

In Lithuania, the consumption of electricity was 11,738 GW h in 2010. The share electricity produced from RES is about 7.4% of gross consumption of electricity in country.

Most people in Lithuania think that the biggest barrier for the development of green electricity market is financial nature. Fewer barriers are seen in administrative procedures. In Lithuania, there are developed legislation basis on production of electricity from RES [21]. Pursuant to Electricity Law of Lithuania the Government approved the procedures for purchasing electricity produced from local and renewable energy sources. The procedures promote the purchase of green electricity with feed in tariffs. The State Commission for Prices and Energy Control established the average prices for purchasing electricity produced from RES and conditions of their application. In Lithuania, the electricity production from RES is mainly based on Kaunas Hydro Power Plant (HPP), small hydro power plants (capacity is less as 10 MW, whose total number is about 80), wind turbines and solid biomass cogeneration units. Kaunas HPP installed capacity is 100.8 MW and annual production of energy varied from 0.330 TW h/year to 0.438 TW h/year. The installed capacity of small hydro power plants is about 27 MW with annual production from 0.060 TW h/year to 0.090 TW h/year. In this time, the wind energy begins to use for electricity production. Installed capacity of wind turbines was 163 MW in 2010, and the energy production was 0.224 TW h. Installed capacity for electricity production from solid biomass was 29 MW and production about 0.147 TW h/year. Beside them, there are four cogeneration units, which produce electricity and heat, in biogas production plants.

4.1.3. Biofuel

In all countries, the biodiesel and ethanol are used as fuel for transport [28]. The total consumption of transport fuels in Lithuania made up 1307 thousand toe (1011 thousand toe of diesel fuel and 295.7 thousand toe of gasoline) in 2010. The minimum share of biofuels has to be 5.75% from total consumption of transport fuels.

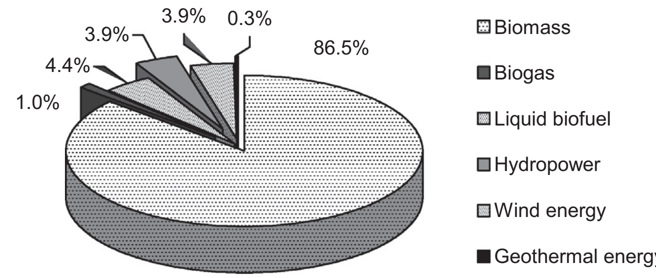


Fig. 12. Distribution of renewable energy final consumption in Lithuania in 2011.

The RES final consumption distribution in Lithuania, in 2011, is shown in Fig. 12.

The firewood, wood and agricultural waste accounted for 86.5% of the total consumption of RES, biofuel—4.4%, hydropower—3.9%, wind energy—3.9%, biogas—1.0%, geothermal energy—0.3%. The largest share of the RES for production of energy in Lithuania makes wood fuel. Also, there are increases in the use of wind energy, small and large hydro energy, biofuels for transport and other ones. The National Strategy for the Development of RES [27] indicates that Lithuanian energy policy places an increasingly great emphasis on the continual development of RES.

4.2. The RES potential in INPP region

The main RES in the INPP region is biomass. Technical potential of biomass in the separate INPP region municipalities is determined by the disposed land where grain crops, energy plants (fast-growing bushes, rapes, corn, etc) and forests (wood, cutting residues) are grown as well as the productivity of that land and duration of plants rotation. Moreover, abandoned land may also provide RES (grass).

RES could also be provided by other resources, such as animal husbandry objects, sewage cleaning plants, industrial companies producing organic waste, located in separate municipalities as well as household waste, sun, wind, hydro energy, geothermal energy, etc. Separate RES (e.g. wood, straw, etc) can be used in their primary form for the generation of electrical energy and heating, while the use of other RES is possible only after their appropriate processing (e.g. wood granules, biogas, biofuel, etc). Moreover, the availability of some RES is changing (solar, wind, hydro energy, etc).

4.2.1. Solar heat and electrical energy

In Lithuania, solar radiation differs only slightly depending on the landscape. In the INPP region, the radiation amounts to about 1000 kW h/m^2 a year.

Solar energy is the primary source of almost all types of RES. Its application for practical needs is divided into direct production of electrical energy (photo electricity) and solar collectors for heating the water. However, currently no solar plants, generating electricity and supplying it to the network, exist in Lithuania.

Up to now photo electricity has not been extensively used for energy needs in Lithuania. First of all, this is determined by poor sponsorship of environment-friendly energy resources. The use of solar energy for heating water is one of the quickest, most straightforward and reasonable methods to reduce consumers' daily costs under the Lithuanian climatic conditions. This would enable saving 50–60% of costs used for heating water annually.

In the calculations of the technical solar energy potential, the following was considered: amount of houses (units); sizes of solar collectors for 1–2 flats houses and blocks of flats (m^2); efficiency of solar collectors (kW h/m^2 annually).

Table 3
Theoretical, technical and economically based potential of solar heat in the INPP region.

	Buildings	Number of houses	Size of solar collectors (m^2)	Efficiency of collectors (kW h/m^2 annually)	Theoretical potential (TW h)	Technical potential (GW h)	Economically based potential (GW h)
Ignalina district municipality	One to two flats houses	6,437	5	450		14	1.4
	Block of flats	3,469	20	450		31	3.1
	Total:				1357	46	4.6
Visaginas municipality	One to two flats houses	32	5	450		0.1	0.01
	Block of flats	10,563	20	450		95	9.5
	Total:				55	95	9.5
Zarasai district municipality	One to two flats houses	5,588	5	450		13	1.3
	Block of flats	3,487	20	450		31	3.1
	Total:				1251	44	4.4
INPP region	One to two flats houses	12,057				27	2.7
	Block of flats	17,519				158	15.6
	Total:				**2664**	**185**	**18.5**

Table 4
Technical potential of wind power plants in the INPP region.

	Electrical energy consumption (GW h/year)	Average capacity of generators (MW)	Coefficient of wind power plant efficiency	Installed capacity of wind power plants, (MW)	Amount of energy produced (thousand toe/year)
Ignalina district municipality	35.01	3.99	0.20	19.95	3.01
Visaginas municipality	60.25	6.88	0.20	34.40	5.18
Zarasai district municipality	36.17	4.13	0.20	20.65	3.11
INPP region	**131.43**	**15.00**	**0.20**	**74.00**	**11.30**

Table 5
Theoretical possibilities of shallow geothermal energy use in the INPP region.

	Dwelling fund. thousand (m^2)	Heat pump capacity for heating a 100 m^2 area. (kW)	Necessary heat pump capacity (MW)
Ignalina district municipality	710.4	7	49.73
Visaginas municipality	598.6	7	41.90
Zarasai district municipality	630.8	7	44.16
INPP region	**1939.8**	**7**	**135.79**

Technical and economically based potential of solar heat in the INPP region were, respectively, 185 GW h/year and 18.5 GW h/year (Table 3).

In many EU countries, it is accepted that to satisfy the electrical energy needs in a single house, about 20 m^2 of photo elements should be installed, while this number equals 60 m^2 in the case of block of flats. In a long-term perspective, it is expected that only 1% of the indicated amount could be installed in the region.

So, estimated technical and economically based potential of solar electricity in the INPP region were around 194 GW h/year and 1.9 GW h/year, respectively. Economically based potential of solar electricity in the INPP region is about 10 times less the solar heat potential.

4.2.2. *Wind energy*

In the INPP region, conditions for the development of wind power plants are not favourable (average wind velocity reaches 3.5–4 m/s); however, wind energy would be possible in this region if advanced wind power plant production technologies were applied, the most suitable locations for plants were selected and the 100 m-high or higher wind turbine towers were built. According to the wind plant power connection scheme, presented by *JSC LITGRID*, the INPP has technical possibilities to connect plants generating up to 75 MW of power in each Ignalina, Visaginas and Zarasai municipality. Wind power plants having up to 225 MW power in total could be connected to the high-tension networks in the INPP region, which determines the theoretical wind energy potential.

Technical wind energy potential was estimated following the assumption that the INPP region could fully satisfy the electrical energy demand, i.e., 74 MW, using RES (Table 4).

In addition, the economically based wind energy potential of the INPP region could be estimated by carrying out a detailed theoretical and wind parameter research (which would require a lot of time and financial resources), involving the selection of appropriate construction sites for wind power plants.

The fact that the construction of a very powerful wind power plant may not pay off in the INPP region does not deny the possibilities to develop wind energy of smaller capacity (up to several tens or hundreds of kilowatts). The requirements for building special-construction wind power plants adjusted to operate under high turbulence, for example, in a city, are not so strict; thus, their construction and connection to low-tension networks are cheaper.

Table 6
Potential of wood fuel use in the INPP region.

	Forestry waste		Firewood		Total primary energy (thousand MW h/year)	Final energy	
	thousand ktm	Primary energy (thousand MW h/year)	thousand ktm	Primary energy (thaus. MW h/year)		thousand MW h/year	thousand toe
Ignalina district municipality	9.6	23.04	39.4	94.56	117.6	88.2	7.58
Visaginas municipality	0.6	1.44	2.3	5.52	6.96	5.22	0.45
Zarasai district municipality	18.1	43.44	24.9	59.76	103.2	77.4	6.65
INPP region	**28.3**	**67.92**	**66.6**	**159.84**	**227.76**	**170.82**	**14.69**

Table 7
Theoretical potential of biogas production from sewage sludge.

	Amount of sludge (t/year)	Amount of biogas (m^3/t)	Biogas in total (m^3)	Amount of primary energy (thousand m^3/toe)	Primary energy in total (thousand toe)
Ignalina district municipality	46	800	36,800	0.48	0.02
Visaginas municipality	299	800	23,9200	0.48	0.115
Zarasai district municipality	50	800	40,000	0.48	0.02
INPP region	**395**	**800**	**316,000**	**0.48**	**0.152**

4.2.3. Geothermal energy

Ground heat may be exploited by using heat pumps: source—heat exchanger—heat pump—consumer. Heat pumps are used for heating separate houses of public objects (area of several hundred m^2). The dominant installations include heat source—ground (system with intermediate heat exchanger), heat source—water basin or air. To heat a 100 m^2 building, an installation of about 7 kW heat generations is necessary. An amount of 1 kW electrical energy is necessary to produce 3–5 kW of thermal energy. The annual increase of heat pump installation in Lithuania is about 20%.

Theoretical possibilities of shallow geothermal energy use in the INPP region require heat pumps of 135.8 MW capacity when the dwelling fund is 1940 thousands m^2 (Table 5).

4.2.4. Biomass

4.2.4.1. Forestry waste. Wood waste is still the least used source of wood fuel. It consists of truncated stem tops, branches (diameter of < 5 cm), stems of small trees (diameter of≤5 cm) and stumps. However, the use of stumps for fuel is not investigated due to the lack of data.

4.2.4.2. Deadwood. There is about 23 m^3/ha of deadwood, i.e., naturally fell and dead trees, their stems and branches, stumps, tops, unreasonably used parts of stems, etc., available in the Lithuanian forests. The share of naturally fell tree stems suitable at least for fuel comprises 8.1 m^3/ha, i.e., the volume of tree stems that fall naturally in the Lithuanian forests exceeds 3 million m^3. Only a relatively small part (23%) of this wood is taken from the forests: the remaining part is left to decay.

4.2.4.3. Energy plantations. The resources of wood fuel could be increased by growing energy plantations. Theoretical potential of final energy from energy plants is 2.31 thousand toe in the INPP region.

4.2.4.4. The potential of wood fuel. The potential of wood fuel use in the INPP region (total primary energy) amounts to 228,000 MW h/year (Table 6).

4.2.4.5. Plant growing waste. In 2008 the annual amounts of straw of the INPP region amounted to 25,000 t (75% in Ignalina and 25% in Zarasai district municipality) and amount of primary energy reaches about 6000 MW h/annually.

In the INPP region, the usage of straw energy potential is possible and recommended only in small central heating supply systems. Moreover, one to two boilers could be installed in Zarasai boiler house next to the wood waste-fired boiler.

4.2.5. Biogas

The potential of dumping grounds of household waste is calculated according to the number of citizens in each district. According to the data of the Ministry of Environment, on average around 300 kg of household waste falls on one citizen of a city, 220 kg—of a town and 70 kg—of a village a year. Such waste can be used for producing energy after it has been separated from other types of household waste and processed in biogas reactors. However, household waste is still not widely sorted, but instead most of it is taken to dumping grounds where it mixes with other non-hazardous waste, such as street and road sweeping, biologically degradable waste from food processing and catering institutions.

Waste managed by the municipalities amount to 25,000 t in the INPP region. Theoretically, it would be possible to consider the adjustment of dumping grounds to the collection of gas, but in reality due to relatively small amounts of waste the closure of dumping grounds in order to install biogas collection equipment would be irrational. On the basis of the collected data on household waste, the INPP region has no possibilities to use gas from dumping grounds for producing energy.

The potential of water-supply waste, in 2008 the amount of cleaned sewage of the INPP region reached 395 t, of which 299 t goes to Visaginas municipality (Table 7).

For the estimation of the amounts of formed sludge, the assumption, proposed by Kaunas Wastewater Treatment Division, that 60 t of sewage provides 10 t of dried sludge and 8 thousand m^3 of biogas when the degree of sewage pollution is 400 mg/l was accepted.

Theoretical potential of biogas production from sewage sludge reaches 0.152 thousand toe of the total primary energy in the whole INPP region.

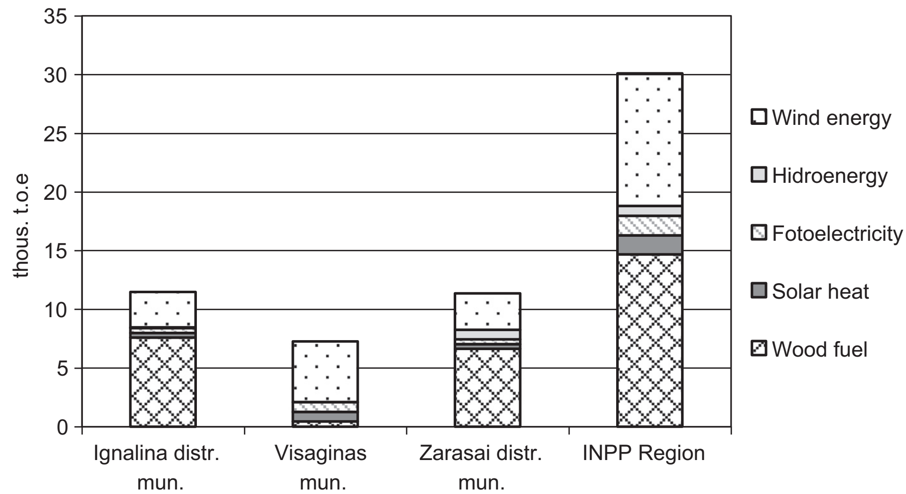


Fig. 13. Technical potential of final energy from RES in the INPP region.

Table 8
Technical potential of final energy from RES in INPP region municipalities, thousand toe.

	Wood fuel	Solar energy		Hydro energy	Wind power	Total amount of energy
		Heat	Photo electricity			
Ignalina district municipality	7.58	0.395	0.438	0.05	3.01	11.473
Visaginas municipality	0.45	0.817	0.816	0	5.18	7.263
Zarasai district municipality	6.65	0.378	0.412	0.8	3.11	11.35
INPP region	**14.68**	**1.59**	**1.67**	**0.85**	**11.30**	**30.09**

Biogas from organic materials (animal manure and bedding, biologically degradable waste), in Lithuania the main source of raw materials for biogas production is animal manure. The large farms, using animal and bird keeping technologies with no bedding and having huge demand for thermal energy, have the greatest prospects to build biogas power plants. If in the INPP region only raw materials were used for biogas power plants, theoretically this would have a great potential. The area of most farms of the INPP region amounts to 20 ha; thus, it may be stated that building of biogas power plant and maintaining it by a single farm would be impossible. Since the farms are too small, only cooperation is possible, because rather vast amounts of raw materials and respective areas of land are necessary. The performed calculations suggest that in order to supply raw materials to a biogas power plant having 500 kW of electric power, 450–500 ha of land is required. In 2008 the annual amount of manure (of cattle, pigs, birds) available in large farms in the INPP region amounted to 36 kt/annually.

5. General remarks on the RES potential in the INPP region

The calculated total technical potential of final energy generated from RES in the region is 30.09 thousand toe (349.95 GW h/year), from which wood fuel amounts to 14.68 thousand toe, solar heat—1.59 thousand toe, photo electricity—1.67 thousand toe, hydro energy—0.85 thousand toe and wind power—11.30 thousand toe (Fig. 13).

In Ignalina and Zarasai districts, RES potential is bigger, in comparison to Visaginas municipality and reaches 11.35 and 11.47 thousand toe, respectively, while Visaginas potential is 7.26 thousand toe (Table 8). Visaginas has less of wood fuel sources and more extensive solar and wind power development possibilities. About 37.55% of total amount goes to wind energy, 48.80%—to wood fuel, 10.83%—to solar energy, 2.82%—to hydro energy.

Final energy demand of the INPP region is about 650 GW h/annually. So, the calculated technical potential from RES is about half the amount necessary to satisfy the needs of the INPP region. Therefore, the INPP region has a considerable technical potential to produce and use energy from local energy sources.

6. Conclusions

A great variety of energy saving and generation technologies and systems could be used in the regions after decommission of nuclear power plants as well as in the Lithuanian Ignalina NPP region. Although biofuel is usually selected aiming at the reduction of fossil fuel consumption, these resources are limited and may be depleted. The introduction of hydro energy and biogas resources could pose environmental and economic problems. Thus, the realization of long-term perspectives requires the implementation of priority measures in the areas of energy saving and consumption. The principal objectives of energy saving and its alternatives in the Ignalina NPP region for the period till 2020 are the following:

- to achieve complete independence of the region from imported fuel by producing thermal and electrical energy using local RES fuel;
- to increase the efficiency of thermal energy production by5%;
- to reduce the thermal energy losses in the transmission networks to the limit of11%;
- to reduce the consumption of thermal energy in blocks of flats and public buildings by20%;
- to save at least 20% of regional electrical energy consumption by applying various measures for electrical energy saving.

To reduce energy consumption in public buildings, investments should be made into improving energy efficiency of these buildings by repairing and/or reconstructing building envelopes and improving their thermal characteristics. Also the reconstruction of energy systems (engineering and technological-engineering) in this way improving energy characteristics of public buildings must be done. CHP plants should be renovated increasing their productivity and the development of high-efficiency cogeneration will be carried out. For the same purpose, boiler houses supplying heat into district heating networks will be modernized considering, on the case-by-case basis, the possibility to generate electricity using efficient CHP mode. The heat pumps for heating public and dwelling houses will be used.

Visaginas town uses centralized thermal energy supplied from the gas-fired boiler house located 8 km away from the town, which results in great thermal energy losses through the network. It would be useful to build a biofuel boiler house in the town territory, which would satisfy the needs of the inhabitants, as well as to reconstruct heat-supply networks and carry out a study on the use of geothermal, solar, wind energy in separate buildings. Having built a nuclear power plant, its waste thermal energy could be used to satisfy the needs of the town. The life cycle of the biofuel combustion equipment installed into the centralized heat-supply system of Ignalina is 10 years. This system will be exploited for the whole period; however, at the same time the heating of the dwelling houses will be gradually replaced with electricity heating by constructing solar- and wind-power plants and heat pumps.

Investigation shows that experience achieved in Ignalina NPP region could be used in other East European countries after the decommission of nuclear power plants, because the climate conditions and energy sectors are similar enough as in the Ignalina NPP region.

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